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WERABLE TECHNOLOGIES IN ATRIAL FIBRILLATION SCREENING: A NARRATIVE REVIEW

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ABSTRACT

Background: Atrial fibrillation (AF) is a major public health challenge and a primary independent risk factor for ischemic stroke. The diagnosis of AF is often hindered by its frequently asymptomatic or paroxysmal nature, which leads to a significant diagnostic gap in traditional monitoring.
Purpose: This review evaluates the clinical reliability of wearable technologies for AF screening and analyzes their impact on modern cardiovascular prevention and healthcare systems.
Methods: A comprehensive literature search was conducted across major medical databases, focusing on landmark clinical trials, meta-analyses, and the latest European Society of Cardiology guidelines.
Results: Contemporary wearable devices utilizing photoplethysmography and mobile ECG have demonstrated high positive predictive values for AF detection in large-scale studies such as the Apple Heart Study and Fitbit Heart Study. Advanced artificial intelligence algorithms further enhance diagnostic precision by reducing motion artifacts. However, successful clinical integration remains limited by socio-ethical challenges, including the digital divide and data privacy concerns.
Conclusion: Wearable technologies represent a breakthrough in population-based screening, yet their clinical efficacy depends on a hybrid care model that integrates digital data with physician judgment.

KEYWORDS
Atrial Fibrillation, Wearable Technologies, Screening, Mobile ECG, Artificial Intelligence

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Introduction

Atrial fibrillation (AF) represents one of the most significant challenges in contemporary cardiology, serving as a key risk factor for ischemic strokes and cases of heart failure (Ko et al., 2025). Despite the clinical importance of this condition, the early diagnosis of AF remains problematic due to its frequently asymptomatic or paroxysmal nature. Traditional tools, such as the standard 12-lead electrocardiogram (ECG) or 24-hour Holter monitoring, offer only a relatively short segment of the heart's bioelectrical activity. Since many AF episodes occur in a paroxysmal form, they often remain undetected during routine examinations, which exposes patients to thromboembolic complications (Francisco-Pascual et al., 2021).

The rapid development of wearable technologies, ranging from consumer electronics to advanced telemedicine systems, has opened entirely new possibilities for population-based cardiovascular screening. Diagnostics, previously limited to sporadic visits to medical facilities, can now undergo seamless integration with the patient's daily activity. Contemporary smartwatch devices, equipped with photoplethysmographic (PPG) sensors and single-channel ECG modules, have evolved from simple fitness monitors into certified tools supporting clinical decisions (Castaneda et al., 2018).

This progress is determined by the implementation of advanced artificial intelligence(AI) and machine learning algorithms, which eliminate motion artifacts with increasing precision, enabling reliable arrhythmia identification in real-world conditions(Turakhia et al., 2019). Nevertheless, the ubiquity of cardiac monitoring generates new systemic challenges. Medical personnel face the problem of critical information overload(data deluge), while users grapple with the psychological effects of constant surveillance over an increasing number of various vital parameters, which may lead to an increase in the occurrence of anxiety states (Pergolizzi Jr. et al., 2023).

The aim of this study is a critical evaluation of the current state of wearable technologies in AF detection by analyzing their clinical reliability in the context of leading population-based studies. Furthermore, the article analyzes the impact of these innovations on the evolution of the patient-physician relationship and the efficiency of healthcare systems. In an era of transformation toward personalized and proactive medicine, understanding the synergy between advanced wearable hardware and cardiovascular prevention becomes essential for modern medical personnel and informed technology users

Materials and Methods

To ensure a rigorous and up-to-date synthesis of the clinical landscape, a comprehensive literature search was performed across medical databases, including PubMed, Scopus, and Google Scholar. The search strategy encompassed peer-reviewed articles published up to 2026, utilizing a combination of keywords such as: "atrial fibrillation," "screening," "wearable devices," "smartwatches," "stroke prevention," and "digital health".

The selection process prioritized high-level evidence, specifically randomized controlled trials (RCTs), systematic reviews, and large-scale population-based cohort studies. Landmark studies, including the Apple Heart Study, Fitbit Heart Study, and Huawei Heart Study, were critically appraised for their clinical reliability and implications for integrated patient management. Furthermore, the review analyzed the most recent clinical guidelines from the European Society of Cardiology (ESC 2024) to contextualize the evolving role of wearables in formal diagnostic pathways.

Inclusion criteria were based on the scientific credibility of the publications and their direct relevance to the pathophysiology of AF, the technical validation of PPG and mECG sensors, and the socio-ethical challenges of digital cardiology. In total, several dozen references were analyzed, with a particular emphasis on publications from the last five years to reflect the rapid technological progress in mobile cardiac monitoring.

Results

Epidemiology

AF is not merely an isolated rhythm disorder; it is recognized as a significant public health problem (Cheng et al., 2024). According to data from the Global Burden of Disease report, the number of individuals diagnosed with AF or AFL worldwide exceeded 52 million in 2021, with the highest prevalence found in high-income countries in North America, Asia, Australia, and Western Europe (Martin et al., 2024). It is projected that the number of people diagnosed with AF in the European Union alone will increase from 8.8 million in 2010 to nearly 18 million in 2060 (Krijthe et al., 2013). It is estimated that the lifetime risk of developing AF in individuals of European descent is approximately 1 in 3 (Martin et al., 2024).

From a clinical perspective, the most alarming is the impact of AF on cerebrovascular incidents. Cohort studies, such as the Framingham Heart Study, have unequivocally demonstrated that the presence of AF increases the risk of ischemic stroke on average fivefold (Wolf et al., 1991). Moreover, ischemic strokes associated with AF are linked to nearly twice the mortality, recurrences were more frequent, and neurological deficits were more severe than in the consequence of a stroke unrelated to AF (Lin et al., 1996).

Pathophysiology

The etiology of AF is based on a complex interaction between triggers and the arrhythmogenic substrate. Pioneering studies by Haïssaguerre identified ectopic discharge foci in the pulmonary vein ostia as the primary trigger initiating electrical chaos in the left atrium (Haïssaguerre et al., 1998). It is precisely these rapid impulses that lead to the formation of numerous re-entry waves, which prevent coordinated contraction of the cardiac muscle.

A key phenomenon that should be emphasized is atrial remodeling. This process, described by Wijffels as the principle “AF begets AF” (atrial fibrillation promotes atrial fibrillation), consists in the fact that persistent arrhythmia shortens the refractory period and induces tissue fibrosis, which permanently remodels the heart structure and hinders the return to sinus rhythm (Wijffels et al., 1995). From the perspective of complications, the most significant consequence is a thrombus in the left atrial appendage, where, according to echocardiographic studies, more than 90% of thrombi responsible for embolic strokes in patients with non-valvular AF originate (Blackshear & Odell, 1996).

Clinical presentation and subclinical AF (Silent AF)

The clinical presentation of AF is extremely heterogeneous. While some patients complain of palpitations, exertional dyspnea, or chest pain, a significant group remains entirely asymptomatic. This phenomenon, referred to as silent AF, affects between 25% and even 40% of all patients according to various estimates (‘2023 ACC/AHA/ACCP/HRS Guideline for the Diagnosis and Management of Atrial Fibrillation’, 2024). The ASSERT study demonstrated that subclinical arrhythmia episodes lasting only a few minutes are associated with a significant increase in stroke risk, despite the absence of any sensations on the part of the patient (Healey et al., 2012). This makes AF a 'silent killer', whose first symptom may only be permanent disability caused by a sudden ischemic stroke.

Diagnostic gap and insufficiency of traditional methods

The primary barrier to effective stroke prevention is the paroxysmal nature of the condition (paroxysmal AF). A standard ECG examination, lasting approximately 10 seconds, has a negligible chance of capturing an episode that occurs sporadically, e.g., once a week. Even 24-hour Holter monitoring may be a period too short to detect the arrhythmia (Gladstone et al., 2021).

The diagnostic gap results from the lack of possibility for continuous cardiac surveillance in out-of-hospital conditions. Studies such as Grond et al., 2013 have proven that extending the monitoring duration drastically increases AF detection; it can even double the number of patients diagnosed with AF after a stroke when extending Holter monitoring to 72 hours compared to 24 hours of cardiac monitoring. It is precisely this necessity for prolonged observation time that constitutes a key stimulus for the development of wearable technologies, which fill the gap between the achievable frequency of medical visits and the patient's daily functioning.

Evolution of digital heart rhythm biomarkers

The transition from stationary cardiac diagnostics to mobile monitoring has been enabled by the radical miniaturization of sensors and the evolution of so-called digital biomarkers. Contemporary wearable devices have ceased to function merely as simple accelerometers counting steps; they have become advanced platforms capable of continuous extraction of physiological data in out-of-hospital conditions. In the context of AF detection, the architecture of these systems is based on two fundamental technological pillars: optical photoplethysmography (PPG) and mobile electrocardiography (mECG). Each of these methods operates on a different physical phenomenon, which directly determines their sensitivity, specificity, and ultimate clinical use scenarios (Isakadze & Martin, 2020).

Photoplethysmography

PPG technology, which constitutes a standard in most modern smartwatches from manufacturers such as Apple, Samsung, or Garmin, is based on optical phenomena occurring in peripheral tissues. This mechanism utilizes LEDs emitting mostly green light (short-wave), which penetrates the tissues, and photodetectors measuring the intensity of the scattered light. This value undergoes cyclical changes in rhythm with the pulse wave, reflecting blood volume changes in the capillaries during the cardiac cycle (Allen, 2007; Ghamari et al., 2018).

From the perspective of AF detection, PPG sensors do not directly record the electrical activity of the heart muscle, but rather its mechanical hemodynamic consequences. The key analytical element here is the assessment of the variability of intervals between successive pulse wave peaks, which are used as an indirect indicator of R-R intervals in the ECG tracing. In the event of AF occurrence, the pulse wave takes on characteristics of complete irregularity (irregularly irregular), which systemic algorithms interpret as a potential arrhythmia incident (Tison et al., 2018).

It should be emphasized, however, that the main challenge for PPG reliability remains the signal-to-noise ratio (SNR). The optical signal is highly susceptible to motion artifacts, changes in tissue perfusion resulting from ambient temperature, and the degree of device adherence to the wrist, which can generate false-positive results (Ghamari et al., 2018). In response to these limitations, manufacturers implement advanced digital filters and impose software restrictions, thanks to which passive AF monitoring 'in the background' usually takes place exclusively during periods of the user's rest or sleep. This strategy aims to maximize the specificity of the examination at the expense of measurement continuity (Turakhia et al., 2019).

Mobile ECG

While PPG serves as a tool for passive screening, the mECG function enables active verification of the heart rhythm. This process requires intentional action by the user, consisting in closing the electrical circuit, most often by placing a finger of the opposite hand on the crown or frame of the device. In this way, the smartwatch records the difference in electrical potentials, generating a tracing corresponding to lead I of a standard ECG (Malmqvist et al., 2024).

The fundamental advantage of mECG is the ability to record a direct visualization of the electrical activity of the atria. In contrast to optical methods, the ECG recording allows the physician to notice the absence of P waves and observe the characteristic fibrillation wave (f-wave), which is a necessary condition for making an AF diagnosis (Duarte et al., 2020). Comparative studies have shown that the signal quality generated by devices such as AliveCor KardiaMobile or Apple Watch is fully sufficient for rhythm assessment, matching professional diagnostic devices, provided the patient remains still (Bray et al., 2021). However, a critical limitation remains skin impedance, the necessity of maintaining a dry electrode surface, and potential myogram interference, which in patients with low wave amplitude may prevent correct interpretation of the presence and morphology of P waves (Tieleman et al., 2014).

The role of Artificial Intelligence and Machine Learning

The key factor determining the advantage of modern wearable systems over traditional heart rate monitors is the implementation of an advanced analytical layer based on Artificial Intelligence (AI). Due to the high noise level of the raw PPG signal, its direct clinical interpretation would be burdened by too large an error. The solution has become algorithms based on Deep Neural Networks (DNN), and in particular on Convolutional Neural Networks (CNN), which are trained on multi-million databases of ECG and PPG recordings for precise recognition of arrhythmia patterns (Hannun et al., 2019).

The analytical process typically proceeds in a two-stage manner. In the first phase, referred to as feature extraction, the algorithm identifies reliable heart beat time points, filtering out noise resulting from the user's motor activity. The second stage is the actual classification, in which the system estimates the probability of AF based on the analysis of rhythm variability and signal morphology (Lyon et al., 2018). Modern systems demonstrate the ability for adaptive learning of the patient's physiological profile, which allows for the effective reduction of false alarms caused, for example, by ventricular extrasystole, which in simple mathematical models was often erroneously identified with AF (Chuang & Yang, 2024).

Comparative analysis: Consumer vs. medical devices

The contemporary market for heart rhythm monitoring devices has undergone a clear polarization into general-purpose systems and specialized medical solutions. Smartwatches produced by Apple, Samsung, or Huawei have gained an advantage due to their prevalence and high social acceptance, which allows for cardiac surveillance over a multi-year perspective. Nevertheless, as suggested by data from the Apple Heart Study, their performance profile predestines them mainly for the role of screening tools in relatively low-risk populations, rather than for definitive clinical diagnostics (Perez et al., 2019).

An alternative is provided by dedicated medical systems, such as ECG patches (e.g., iRhythm Zio Patch), which are prescribed by cardiologists for specific diagnostic purposes. These devices, applied directly to the chest, enable continuous ECG recording for a period of up to 14 days. Despite lower user comfort, their sensitivity in detecting short AF incidents is significantly higher, as they analyze the electrical activity of the heart throughout the entire study period, avoiding the selective sampling limited mainly to periods of inactivity typical for watches (Steinhubl et al., 2018). An intermediate solution is provided by KardiaMobile-type devices, which allow for the performance of even a 6-lead ECG recording at any time. They constitute invaluable support for patients with rare but strongly symptomatic arrhythmia paroxysms, offering recording quality acceptable in the full diagnostic process (Koltowski et al., 2021).

Certification and regulatory frameworks

The process of recognition of wearable technologies by the medical community is inextricably linked with rigorous certification by bodies such as the FDA (Food and Drug Administration) in the USA or obtaining the CE mark in Europe. Most leading manufacturers have already received appropriate FDA clearances for their AF detection algorithms. Crucial, however, is the semantic distinction: these devices are certified as systems supporting monitoring, rather than as autonomous diagnostic tools. This imposes an obligation on manufacturers to comply with cybersecurity standards and the protection of sensitive data, which in the reality of cloud computing data processing becomes a new challenge at the intersection of medicine and information technologies (*MDCG, M. 11 Guidance on Qualification and Classification of Software in Regulation (EU) 2017/745–MDR and Regulation (EU) 2017/746–IVDR.*, 2019; U.S. Food and Drug Administration., 2022).

Technical limitations and the dark side of innovation

Despite dynamic progress, wearable technologies are burdened by significant technical limitations that may affect their social fairness and medical effectiveness. One of the most serious problems is the impact of skin pigmentation on PPG signal quality; studies indicate that in individuals with darker skin tones, green light absorption is different, which may lead to reduced measurement precision and potential algorithmic discrimination (Koerber et al., 2023). Furthermore, the phenomenon of overdiagnosis remains a significant challenge. Algorithms often identify very short, clinically silent micro-fibrillation episodes, which generates iatrogenic stress for the patient and an unjustified burden on the healthcare system with visits that do not translate into a real change in prognosis (Ilyas et al., 2024).

The Big Data era in preventive cardiology

For decades, clinical trials in cardiology relied on groups ranging from several hundred to several thousand patients, monitored under strictly controlled clinical conditions. The emergence of wearable technologies has enabled the conduct of studies on an unprecedented scale, engaging hundreds of thousands of participants in their natural environment. This change in scale has allowed for the assessment of the actual effectiveness of algorithms in populations diversified in terms of age, activity, and comorbidities (Dai et al., 2022; Frederix et al., 2019).

Apple Heart Study: A pioneering proof of concept

The Apple Heart Study (AHS), published in 2019, constituted a turning point in digital cardiology. It included over 419,000 participants, becoming one of the largest screening studies in the history of medicine. The primary goal was to assess the ability of the Apple Watch algorithm to identify AF using a PPG sensor (Perez et al., 2019).

The AHS results provided key data: irregular rhythm notifications were received by only 0.52% of participants, which reassured critics fearing mass false alarms in the young population. Importantly, in individuals who received a notification and returned an ECG patch for verification, the positive predictive value (PPV) was 84%. However, this study also demonstrated challenges, such as the fact that a large proportion of participants who received an alert did not even continue remote contact with the researchers, highlighting the problem of patient dropping out in clinical trials using digital technologies (Meyerowitz-Katz et al., 2020; Turakhia et al., 2019).

Fitbit Heart Study and the evolution of passive monitoring

The trend was continued by the Fitbit Heart Study (2022), which included 455,000 individuals. In contrast to the AHS, it focused on a newer PPG algorithm that analyzed data exclusively during periods of inactivity (e.g., during sleep). Such a strategy aimed to maximize the specificity of the measurement (Lubitz et al., 2022).

The results confirmed the high effectiveness of this type of passive monitoring. The PPV for AF detection reached as much as 98%. This study proved that wearable technology can act as a 'silent guardian' that does not require any activity from the user (such as placing a finger on an electrode), which drastically increases the chance of detecting nocturnal and asymptomatic episodes, the most difficult to capture in the standard diagnostic pathway (Barrera et al., 2025).

Huawei Heart Study and the integrated care model

While American studies focused mainly on detection itself, the Chinese Huawei Heart Study (mAFA-II) went a step further, analyzing the entire treatment process. Over 187,000 Huawei smartwatch users participated in the study. A key innovation was the combination of the alert from the watch with a mobile medical platform that directed the patient directly to cooperating hospitals (Guo et al., 2019).

It was demonstrated that such an integrated care model (the so-called ABC pathway: Anticoagulation, Better symptom management, Cardiovascular risk reduction) significantly reduces the risk of stroke and hospitalization (Romiti et al., 2023). From the perspective of medical sociology, this constitutes a key argument: the clinical effectiveness of new digital technologies is conditioned by their full integration with the existing healthcare system, which precludes perceiving wearable devices merely as isolated measurement tools (Guo et al., 2017).

Randomized controlled trials: eBRAVE-AF and STROKESTOP

In recent years, we have also seen randomized controlled trials (RCTs), which represent the highest level of medical evidence. The eBRAVE-AF study conducted in Germany demonstrated that smartphone- and watch-based screening allowed for AF detection in twice as many individuals as in the group receiving standard medical care (Rizas et al., 2022).

In turn, the Swedish STROKESTOP study provided evidence that systematic population screening of older individuals using portable ECG devices can lead to a reduction in the number of ischemic strokes nationwide (Svennberg et al., 2021). This study is frequently cited as an argument for the reimbursement of mobile technologies by national insurance systems (Lyth et al., 2022).

Discussion

The 'Worried Well' problem and interpretational challenges

Despite successes, the literature points to significant social challenges resulting from the conducted studies. Overdiagnosis of short, clinically insignificant micro-fibrillation episodes in young and healthy individuals can generate increased health anxiety(Rosman et al., 2024). Studies such as LOOP suggest that not every detected AF requires aggressive anticoagulant treatment, and clinically unjustified pharmacotherapy may lead to unnecessary bleeding complications in individuals with a low risk profile for thromboembolic complications (Svendsen et al., 2021).

A key challenge remains the determination of a clinical cutoff point (the so-called AF burden), defining the minimum duration of arrhythmia necessary to implement anticoagulant prophylaxis. The current scientific discourse focuses on seeking a compromise between early intervention and avoiding iatrogenic bleeding complications, analyzing the justification for treatment in the case of short-term episodes lasting several or a dozen or so minutes (Kirchhof et al., 2023).

Impact of studies on cardiology guidelines

A direct result of the aforementioned studies was the change in the official guidelines of the European Society of Cardiology (ESC). In the latest updates (2020/2024), wearables have received an official place in the diagnostic pathway. These guidelines emphasize that although a watch does not replace a medical diagnosis, a certified ECG recording from a wearable device can be the basis for diagnosing AF if it is verified by a cardiologist (Van Gelder et al., 2024).

Socio-ethical challenges and digital exclusion

Although the clinical benefits of wearable technologies are difficult to dispute, their integration with society and modern healthcare raises significant ethical concerns. The most pressing problem is the so-called 'digital divide,' a socioeconomic barrier that limits access to life-saving technologies. Currently, advanced smartwatches with certified ECG algorithms are premium products, often unattainable for low-income populations, older individuals, or residents of developing countries. Paradoxically, it is these very groups that may be burdened with the highest risk of untreated cardiovascular diseases, while simultaneously lacking the tools for their early detection and monitoring (Mitchell et al., 2019; Western et al., 2025).

Another key socio-technical challenge is the issue of privacy and ownership of medical data. At the moment when heart rhythm data is transmitted to cloud computing managed by international technology corporations, questions arise about who actually owns the digital recording of the user's heart function. How is this sensitive information protected against use by third parties, e.g., insurance companies? The transition from the role of a consumer to the role of a patient requires the creation of a solid legal framework that will guarantee data security without hampering innovation (Price & Cohen, 2019).

Finally, the phenomenon of information overload in daily clinical practice cannot be overlooked. Healthcare systems, designed to handle incidental visits, are currently not prepared to process the continuous stream of data generated by patients. Without the standardization of data triage protocols, there is a risk that the 'revolution' in AF detection will lead to physician burnout and an increase in public costs resulting from performing unnecessary tests in individuals with clinically insignificant changes in the recording of cardiac activity (Asgari et al., 2024; Nijor et al., 2022).

Conclusions

The transformation of wearable devices from fitness gadgets into certified medical tools represents a breakthrough change in the 21st-century healthcare system. By filling the 'diagnostic gap' inherently associated with traditional diagnostic methods in cardiology, smartwatches and medical patches have proven their ability for AF screening on a massive, population-wide scale. Evidence from landmark studies, such as the Apple Heart Study and Fitbit Heart Study, confirms that passive monitoring is not only feasible but also highly effective in identifying asymptomatic patients at risk of stroke.

However, it must be emphasized that technology itself is not a panacea. The success of digital cardiology depends on the implementation of a hybrid care model, namely one that combines the continuous stream of data from AI-supported sensors with the physician's clinical experience and judgment (Lopez-Jimenez et al., 2020). In the future, the focus must shift from detection alone to integrated patient management, so that every notification of a clinically significant irregular rhythm leads to an evidence-based intervention that benefits the patient.

In conclusion, wearable technologies have expanded access to cardiac prevention, making patients active participants in the treatment process. Although challenges regarding data privacy, overdiagnosis, and economic barriers remain relevant, the potential to reduce the global burden of stroke is immense. The future of cardiology is on the patient's wrist, but its heart lies in close cooperation between technology, the physician, and an informed society (Topol, 2019).

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